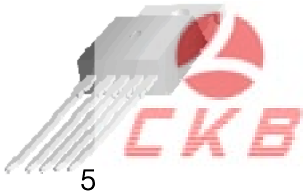
3.0A, 150kHz, Step-Down Switching Regulator LM2596

FEATURES

- 3.3V, 5.0V, 12V, and Adjustable Output Versions
- Adjustable Version Output Voltage Range, 1.2 to 37V +/- 4%. Maximum Over Line and Load Conditions
- Guaranteed 3.0A Output Current
- Wide Input Voltage Range
- Requires Only 4 External Components
- 150kHz Fixed Frequency Internal Oscillator
- TTL Shutdown Capability, Low Power Standby Mode
- High Efficiency
- Uses Readily Available Standard Inductors
- Thermal Shutdown and Current Limit Protection
- Moisture Sensitivity Level 3

TO-220 PKG



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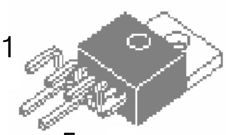
TO-220V PKG



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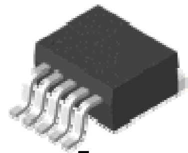
TO-263 PKG



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1. Vin 2. Output 3. Ground
4. Feedback 5. On/Off

Applications

- Simple High-Efficiency Step-Down(Buck) Regulator
- Efficient Pre-Regulator for Linear Regulators
- On-Card Switching Regulators
- Positive to Negative Converter(Buck-Boost)
- Negative Step-Up Converters
- Power Supply for Battery Chargers

ORDERING INFORMATION

Device	Marking	Package
LM2596T-X.X	LM2596T-X.X	TO-220
LM2596TV-X.X	LM2596T-X.X	TO-220V
LM2596R	LM2596R-X.X	TO-263

DESCRIPTION

The LM2596 series of regulators are monolithic integrated circuits ideally suited for easy and convenient design of a step-down switching regulator(buck converter).

All circuits of this series are capable of driving a 3.0A load with excellent line and load regulation. These devices are available in fixed output voltages of 3.3V, 5.0V,12V, and an adjustable output version.

These regulators were designed to minimize the number of external components to simplify the power supply design. Standard series of inductors optimized for use with the LM2596 are offered by several different inductor manufacturers.

Since the LM2596 converter is a switch-mode power supply, its efficiency is significantly higher in comparison with popular three-terminal limear regulators, especially with higher input voltages.

In many cases, the power dissipated is so low that no heatsink is required or its size could be reduced dramatically. A standard series of inductors optimized for use with the TJ2596 are available from several different manufacturers. This feature greatly simplifies the design of switch-mode power supplies. The LM2596 features include a guaranteed +/- 4% tolerance on output voltage within specified input voltages and output load conditions, and +/-15% on the oscillator frequency (+/- 2% over 0℃ to 125℃).

External shutdown is included, featuring 80㎂ (typical) standby current. Self protection features include a two stage frequency reducing current limit for output switch and an over temperature shutdown for complete protection under fault conditions.

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Typical Application (Fixed Output Voltage Versions)

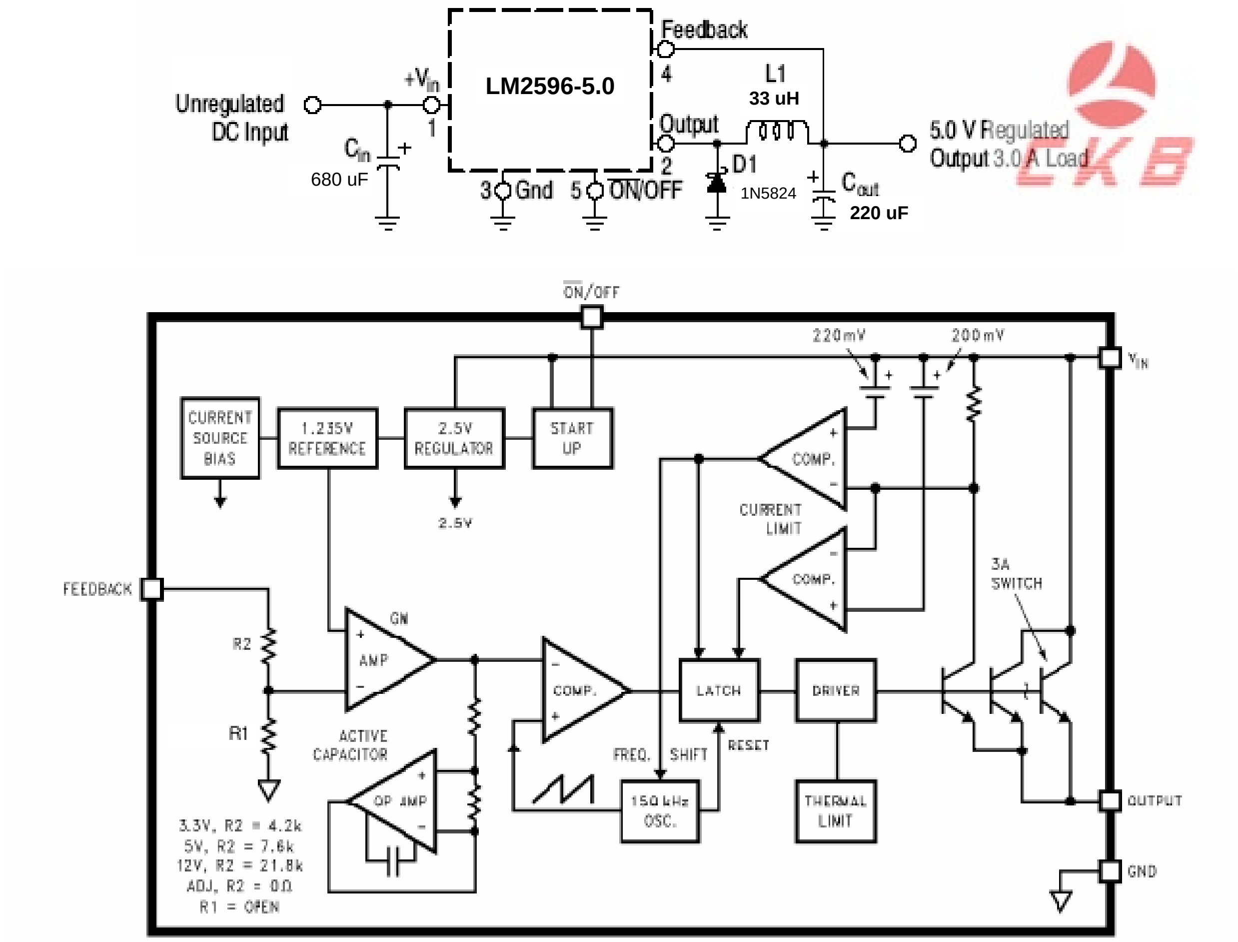


Figure 1. Block Diagram and Typical Application

ABSOLUTE MAXIMUM RATINGS

(Absolute Maximum Ratings indicate limits beyond which damage to the device may occur.)

Rating	Symbol	Value	Unit
Maximum Supply Voltage	Vin	45	V
On/Off Pin Input Voltage	–	−0.3V ≤ V ≤ +Vin	V
Output Voltage to Ground (Steady-State)	–	− 1.0	V
Power Dissipation			
TO-220 5Lead	P_D	Internally Limited	W
Thermal Resistance, Juntion to Ambient	$P_{\theta JA}$	65	℃/W
Thermal Resistance, Juntion to Case	$P_{\theta JC}$	5.0	℃/W
TO-263 5Lead	P_D	Internally Limited	W
Thermal Resistance, Juntion to Ambient	$P_{\theta JA}$	70	℃/W
Thermal Resistance, Juntion to Case	$P_{\theta JC}$	5.0	℃/W
Storage Temperature Range	T_{stg}	−60 to +150	℃
Minimum ESD Rating(Human Body Model : C=100 pF, R=1.5kΩ)	–	2.0	kV
Lead Temperature (Soldering,10seconds)	–	260	℃
Maximum Junction Temperature	T_J	150	℃

OPERATING RATINGS (Operating Ratings indicate conditions for which the device is intended to be fu but do not guarantee specific performance limits. For guaranteed specifications and test conditions, see Characteristics.)

Rating	Symbol	Value	Unit
Operating Junction Temperature Range	T_J	−40 to +125	℃
Supply Voltage	Vin	27	V

ELECTRICAL CHARACTERISTICS / SYSTEM PARAMETERS ([Note 1] Test Circuit Figure 2)
(Unless otherwise specified, Vin = 12V for the 3.3V, 5.0V, and Adjustable version, Vin = 25V for the 12V ILoad = 500 mA. For typical values T_J = 25°C, for min/max values T_J is the operating junction temperat range that applies [Note 2], unless otherwise noted.)

Characteristics	Symbol	Min	TYP	Max	Unit
LM2596−3.3V ([Note 1] Test Circuit Figure 2)					
Output Voltage (Vin = 12V, I_{LOAD}=0.5A, T_J=25℃)	Vout	3.234	3.3	3.366	V
Output Voltage (6.0V≤Vin≤40V, 0.5A≤I_{LOAD}≤3.0A	Vout				V
T_J=25℃		3.168	3.3	3.432	
T_J= −40℃ ~ +125℃		3.135	−	3.465	
Efficiency (Vin=12V, I_{LOAD}=3.0A)	η	−	73	−	%

Characteristics	Symbol	Min	TYP	Max	Unit
LM2596−5.0V ([Note 1] Test Circuit Figure 2)					
Output Voltage (Vin = 12V, I_{LOAD}=0.5A, T_J=25℃)	Vout	4.9	5.0	5.1	V
Output Voltage (8.0V≤Vin≤40V, 0.5A≤I_{LOAD}≤3.0A	Vout				V
T_J=25℃		4.8	5.0	5.2	
T_J= −40℃ ~ +125℃		4.75	−	5.25	
Efficiency (Vin=12V, I_{LOAD}=3.0A)	η	−	80	−	%

Characteristics	Symbol	Min	TYP	Max	Unit
LM2596−12V ([Note 1] Test Circuit Figure 2)					
Output Voltage (Vin = 25V, I_{LOAD}=0.5A, T_J=25℃)	Vout	11.76	12	12.24	V
Output Voltage (15V≤Vin≤40V, 0.5A≤I_{LOAD}≤3.0A	Vout				V
T_J=25℃		11.52	12	12.48	
T_J= −40℃ ~ +125℃		11.4	−	12.6	
Efficiency (Vin=12V, I_{LOAD}=3.0A)	η	−	90	−	%

Characteristics	Symbol	Min	TYP	Max	Unit
LM2596−ADJ ([Note 1] Test Circuit Figure 2)					
Feedback Voltage (Vin=12V, I_{LOAD}=0.5A, T_J=25℃)	Vout	1.217	1.23	1.243	V
Feedback Voltage(8.0V≤Vin≤40V, 0.5A≤I_{LOAD}≤3.0A, Vou	Vout				V
T_J=25℃		1.193	1.23	1.267	
T_J= −40℃ ~ +125℃		1.18	−	1.28	
Efficiency (Vin=12V, I_{LOAD}=3.0A, Vout=5.0V)	η	−	73	−	%

ELECTRICAL CHARACTERISTICS / Device Parameters

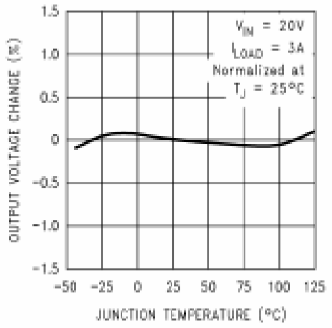
(Unless otherwise specified, Vin = 12V for the 3.3V, 5.0V, and Adjustable version, Vin = 25V for the 12V I_{Load} = 500 mA. For typical values Tj = 25°C, for min/max values T_J is the operating junction temperature that applies [Note 2], unless otherwise noted.)

Characteristics	Symbol	Min	TYP	Max	Unit
All Output Voltage Versions					
Feedback Bias Current (Vout=5.0V [Adjustable Version Only]) T_J=25℃ T_J= 0 ~ +125℃	I_b	 11.52 11.4	 12 –	 12.48 12.6	nA
Oscillator Frequency [Note 3] T_J=25℃ T_J= 0 ~ +125℃	Fosc	 127 110	 150 –	 173 173	kHz
Saturation Voltage (Iout=3.0A [note 4]) T_J=25℃ T_J= 0 ~ +125℃	Vsat	 – –	 1.16 –	 1.4 1.5	V
Max Duty Cycle ("0") [Note 5]	DC	–	100	–	%
Current Limit (Peak Current [Note 3 and 4]) T_J=25℃ T_J= 0 ~ +125℃	I_{CL}	 3.6 3.4	 4.5 –	 6.9 7.5	A
Output Leakage Current [Note 6 and 7], T_J=25℃ Output = 0V Output = –1.0V	I_L	 – –	 – 2	 50 30	mA
Quiescent Current [Note 6] T_J=25℃ T_J= 0 ~ +125℃	I_Q	 – –	 5 –	 – 10	mA
Standby Quiescent Current (ON/OFF Pin = 5.0V ("off")) T_J=25℃ T_J= 0 ~ +125℃	I_{STBY}	 – –	 80 –	 200 250	µA
ON/OFF Pin Logic Input Level (Test circuit Figure 2) Vout=0V T_J=25℃ T_J= 0 ~ +125℃ Vout=Nominal Output Voltage T_J=25℃ T_J= 0 ~ +125℃	 V_{IH} V_{IL}	 – – 2.0 2.0	 1.3 – 1.3 –	 0.6 0.6 – –	V
ON/OFF Pin Input Current (Test Circuit Figure 2) V_{LOGIC} = 2.5V (Regulator OFF) V_{LOGIC} = 0.5V (Regulator ON)	 I_{IH} I_{IL}	 – –	 5 0.02	 15 5.0	µA

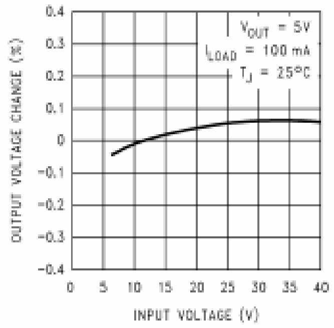
1. External components such as the catch diode, inductor, input and output capacitors can affect switc regulator system performance. When the LM2596 is used as shown in the Figure 1 test circuit, syster performance will be as shown in system parameters section .
2. Tested junction temperature range for the TJ2596 : T_{LOW} = –40°C T_{HIGH} = +125°C
3. The oscillator frequency reduces to approximately 18kHz in the event of an output short or an overloa causes the regulated output voltage to drop approximately 40% from the nominal output voltage. Thi protection feature lowers the average dissipation of the IC by lowering the minimum duty cycle from approximately 2%.
4. Output (Pin 2) sourcing current. No diode, inductor or capacitor connected to output pin.
5. Feedback (Pin 4) removed from output and connected to 0 V.
6. Feedback (Pin 4) removed from output and connected to +12V for the Adjustable, 3.3V, and 5.0V ve +25 V for the 12V versions, to force the output transistor "off".C195
7. Vin = 40 V.

TYPICAL PERFORMANCE CHARACTERISTICS (Circuit of Figure 2)

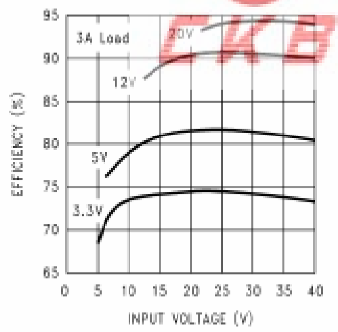
Normalized Output Voltage



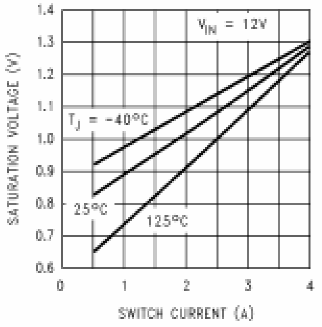
Line Regulation



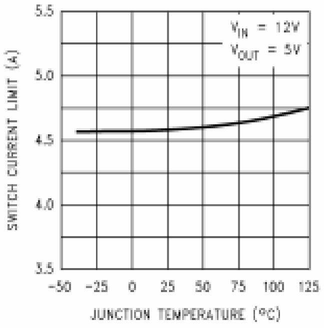
Efficiency



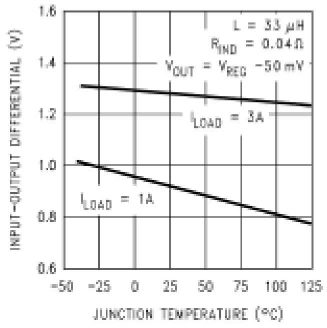
Switch Saturation Voltage



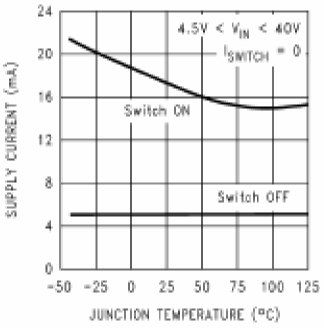
Switch Current Limit



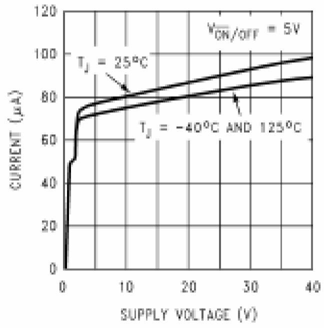
Dropout Voltage



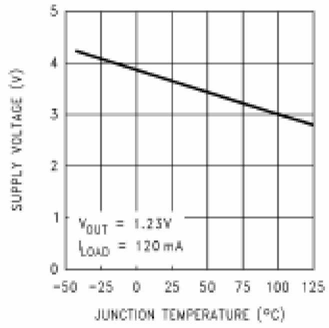
Operating Quiescent Current



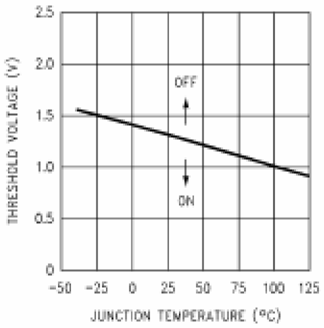
Shutdown Quiescent Current



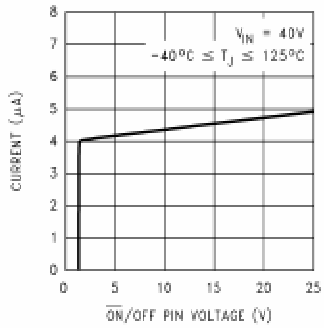
Minimum Operating Supply Voltage



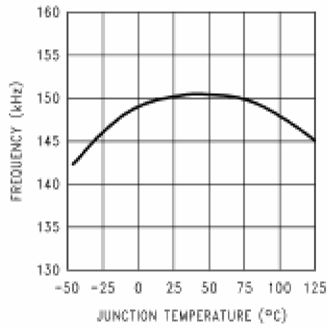
ON /OFF Threshold Voltage



ON /OFF Pin Current (Sinking)

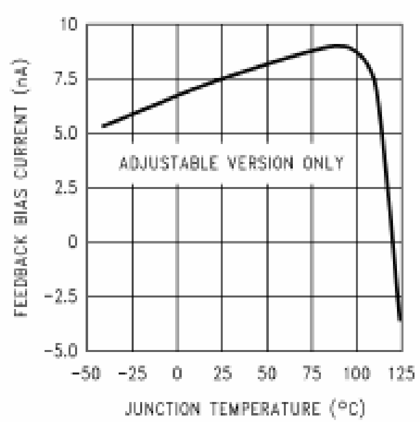


Switching Frequency

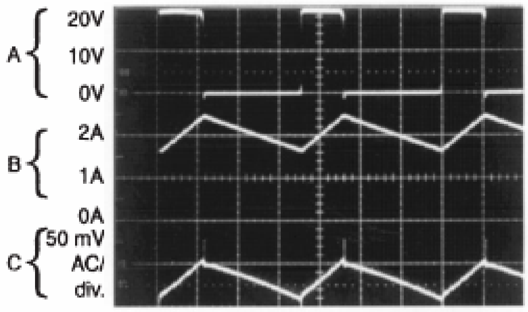


TYPICAL PERFORMANCE CHARACTERISTICS (Circuit of Figure 2)

Feedback Pin Bias Current



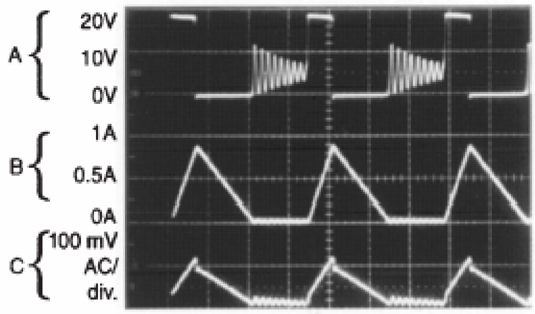
Continuous Mode Switching Waveforms
V_{IN} = 20V, V_{OUT} = 5V, I_{LOAD} = 2A
L = 32 μH, C_{OUT} = 220 μF, C_{OUT} ESR = 50 mΩ



Horizontal Time Base: 2 μs/div.

A: Output Pin Voltage, 10V/div.
B: Inductor Current 1A/div.
C: Output Ripple Voltage, 50 mV/div.

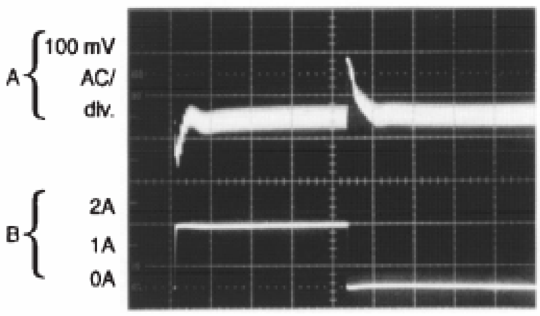
Discontinuous Mode Switching Waveforms
V_{IN} = 20V, V_{OUT} = 5V, I_{LOAD} = 500 mA
L = 10 μH, C_{OUT} = 330 μF, C_{OUT} ESR = 45 mΩ



Horizontal Time Base: 2 μs/div.

A: Output Pin Voltage, 10V/div.
B: Inductor Current 0.5A/div.
C: Output Ripple Voltage, 100 mV/div.

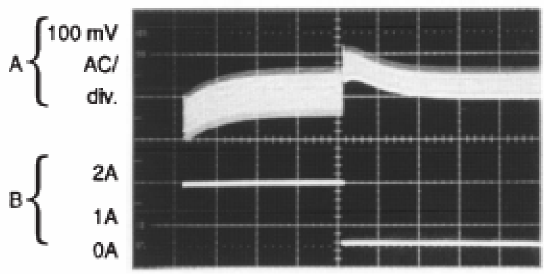
Load Transient Response for Continuous Mode
V_{IN} = 20V, V_{OUT} = 5V, I_{LOAD} = 500 mA to 2A
L = 32 μH, C_{OUT} = 220 μF, C_{OUT} ESR = 50 mΩ



Horizontal Time Base: 100 μs/div.

A: Output Voltage, 100 mV/div. (AC)
B: 500 mA to 2A Load Pulse

Load Transient Response for Discontinuous Mode
V_{IN} = 20V, V_{OUT} = 5V, I_{LOAD} = 500 mA to 2A
L = 10 μH, C_{OUT} = 330 μF, C_{OUT} ESR = 45 mΩ



Horizontal Time Base: 200 μs/div.

A: Output Voltage, 100 mV/div. (AC)
B: 500 mA to 2A Load Pulse

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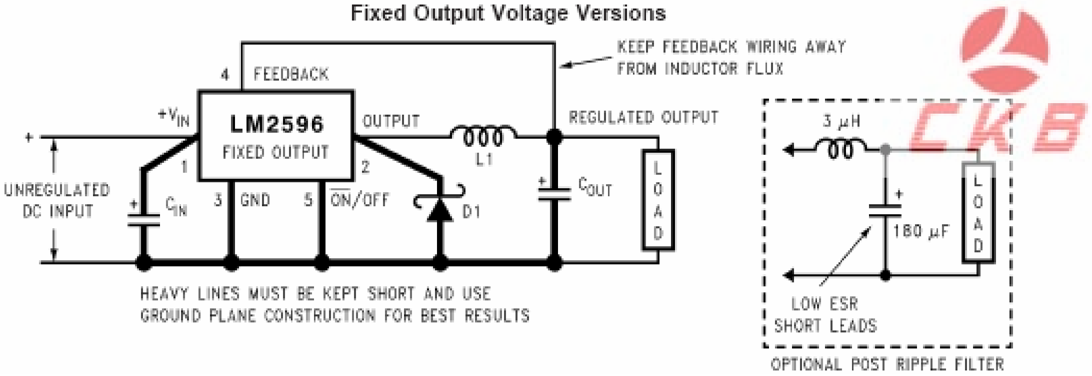
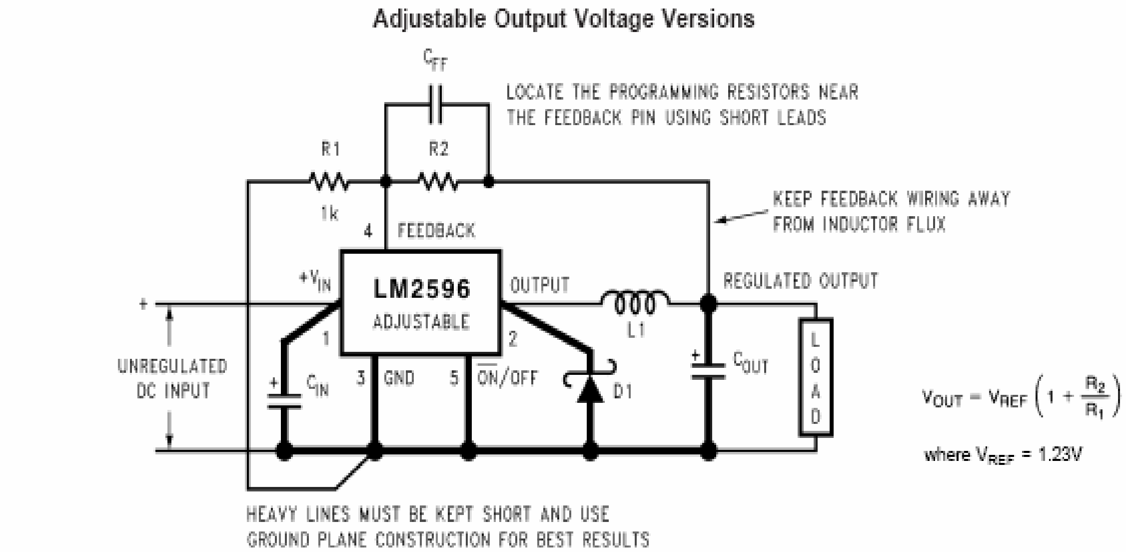
Test Circuit and Layout Guidelines



Cin = 470㎌, 50V, Cout = 220㎌, 25V (Aluminum Electrilytic Nichicon "PL Series"
D1 = 5A, 40V Schottky Rectifier, IN5825
L1 = 68uH, L38



Cin = 470㎌, 50V, Cout = 220㎌, 35V (Aluminum Electrilytic Nichicon "PL Series"
D1 = 5A, 40V Schottky Rectifier, IN5825
L1 = 68uH, R1 = 1㏀, 1% R2 = R1 x (Vout / Vref – 1)

Figure 2. Typical Test Circuits and Layout Guide

As in any switching regulator, layout is very important. Rapidly switching currents associated with wiring can generate voltage transients which can cause problems. For minimal inductance and ground loops, t indicated by heavy lines should be wide printed circuit traces and should be kept as short as possible. For best results, external components should be located as close to the switching IC as possible using g plane construction or single point grounding. If open core inductors are used, special care must be take the location and positioning of this type of inductor. Allowing the inductor flux to intersect sensitive feedl IC groundpath and COUT wiring can cause problems.
When using the adjustable version, special care must be taken as to the location of the feedback resistc associated wiring. Physically locate both resistors near the IC, and route the wiring away from the induct especially an open core type of inductor.

PIN FUNCTION DESCRIPTION

	Symbol	Description
1	Vin	This pin is the positive input supply for the LM2596 step-down switching regulator.In order to minimize voltage transients and to supply the switching currents needed by the regulator, a suitable input bypass capacitor must be present .(Cin in Figure 1).
2	Output	This is the emitter of the internal switch. The saturation voltage Vsat of this output switch is typically 1.5 V. It should be kept in mind that the PCB area connected to this pin should be kept to a minimum in order to minimize coupling to sensitive circuitry.
3	Gnd	Circuit ground pin. See the information about the printed circuit board layout.
4	Feedback	This pin senses regulated output voltage to complete the feedback loop. The signal is divided by the internal resistor divider network R2, R1 and applied to the non-inverting input of the internal error amplifier. In the Adjustable version of the LM2596 switching regulator this pin is the direct input of the error amplifier and the resistor network R2, R1 is connected externally to allow programming of the output voltage.
5	ON/OFF	It allows the switching regulator circuit to be shut down using logic level signals, thus dropping the total input supply current to approximately 80mA. The threshold voltage is typically 1.4V. Applying a voltage above this value (up to +Vin) shuts the regulator off. If the voltage applied to this pin is lower than 1.4V or if this pin is left open, the regulator will be in the "on" condition

DESIGN PROCEDURE (FIXED OUTPUT)

PROCEDURE (Fixed Output Voltage Version)	EXAMPLE (Fixed Output Voltage Version)
Given: V_{OUT} = Regulated Output Voltage (3.3V, 5V or 12V) V_{IN}(max) = Maximum DC Input Voltage I_{LOAD}(max) = Maximum Load Current	**Given:** V_{OUT} = 5V V_{IN}(max) = 12V I_{LOAD}(max) = 3A
1. Inductor Selection (L1) **A.** Select the correct inductor value selection guide from Figures *Figure 4*, *Figure 5*, or *Figure 6*. (Output voltages of 3.3V, 5V, or 12V respectively.) For all other voltages, see the design procedure for the adjustable version. **B.** From the inductor value selection guide, identify the inductance region intersected by the Maximum Input Voltage line and the Maximum Load Current line. Each region is identified by an inductance value and an inductor code (LXX). **C.** Select an appropriate inductor from the four manufacturer's part numbers listed in *Figure 8*.	**1. Inductor Selection (L1)** **A.** Use the inductor selection guide for the 5V version shown in *Figure 5*. **B.** From the inductor value selection guide shown in *Figure 5*, the inductance region intersected by the 12V horizontal line and the 3A vertical line is 33 μH, and the inductor code is L40. **C.** The inductance value required is 33 μH. From the table in *Figure 8*, go to the L40 line and choose an inductor part number from any of the four manufacturers shown. (In most instance, both through hole and surface mount inductors are available.)
2. Output Capacitor Selection (C_{OUT}) **A.** In the majority of applications, low ESR (Equivalent Series Resistance) electrolytic capacitors between 82 μF and 820 μF and low ESR solid tantalum capacitors between 10 μF and 470 μF provide the best results. This capacitor should be located close to the IC using short capacitor leads and short copper traces. Do not use capacitors larger than 820 μF . **For additional information, see section on output capacitors in application information section.** **B.** To simplify the capacitor selection procedure, refer to the quick design component selection table shown in *Figure 2*. This table contains different input voltages, output voltages, and load currents, and lists various inductors and output capacitors that will provide the best design solutions. **C.** The capacitor voltage rating for electrolytic capacitors should be at least 1.5 times greater than the output voltage, and often much higher voltage ratings are needed to satisfy the low ESR requirements for low output ripple voltage. **D.** For computer aided design software, see *Switchers Made Simple*™ version 4.3 or later.	**2. Output Capacitor Selection (C_{OUT})** **A. See section on output capacitors in application information section.** **B.** From the quick design component selection table shown in *Figure 2*, locate the 5V output voltage section. In the load current column, choose the load current line that is closest to the current needed in your application, for this example, use the 3A line. In the maximum input voltage column, select the line that covers the input voltage needed in your application, in this example, use the 15V line. Continuing on this line are recommended inductors and capacitors that will provide the best overall performance. The capacitor list contains both through hole electrolytic and surface mount tantalum capacitors from four different capacitor manufacturers. It is recommended that both the manufacturers and the manufacturer's series that are listed in the table be used. In this example aluminum electrolytic capacitors from several different manufacturers are available with the range of ESR numbers needed. 330 μF 35V Panasonic HFQ Series 330 μF 35V Nichicon PL Series **C.** For a 5V output, a capacitor voltage rating at least 7.5V or more is needed. But even a low ESR, switching grade, 220 μF 10V aluminum electrolytic capacitor would exhibit approximately 225 mΩ of ESR (see the curve in *Figure 14* for the ESR vs voltage rating). This amount of ESR would result in relatively high output ripple voltage. To reduce the ripple to 1% of the output voltage, or less, a capacitor with a higher value or with a higher voltage rating (lower ESR) should be selected. A 16V or 25V capacitor will reduce the ripple voltage by approximately half.

DESIGN PROCEDURE (FIXED OUTPUT)

PROCEDURE (Fixed Output Voltage Version)	EXAMPLE (Fixed Output Voltage Version)
3. Catch Diode Selection (D1) **A.** The catch diode current rating must be at least 1.3 times greater than the maximum load current. Also, if the power supply design must withstand a continuous output short, the diode should have a current rating equal to the maximum current limit of the LM2596. The most stressful condition for this diode is an overload or shorted output condition. **B.** The reverse voltage rating of the diode should be at least 1.25 times the maximum input voltage. **C.** This diode must be fast (short reverse recovery time) and must be located close to the LM2596 using short leads and short printed circuit traces. Because of their fast switching speed and low forward voltage drop, Schottky diodes provide the best performance and efficiency, and should be the first choice, especially in low output voltage applications. Ultra-fast recovery, or High-Efficiency rectifiers also provide good results. Ultra-fast recovery diodes typically have reverse recovery times of 50 ns or less. Rectifiers such as the 1N5400 series are much too slow and should not be used.	**3. Catch Diode Selection (D1)** **A.** Refer to the table shown in *Figure 11*. In this example, a 5A, 20V, 1N5823 Schottky diode will provide the best performance, and will not be overstressed even for a shorted output.
4. Input Capacitor (C_{IN}) A low ESR aluminum or tantalum bypass capacitor is needed between the input pin and ground pin to prevent large voltage transients from appearing at the input. This capacitor should be located close to the IC using short leads. In addition, the RMS current rating of the input capacitor should be selected to be at least ½ the DC load current. The capacitor manufacturers data sheet must be checked to assure that this current rating is not exceeded. The curve shown in *Figure 13* shows typical RMS current ratings for several different aluminum electrolytic capacitor values. For an aluminum electrolytic, the capacitor voltage rating should be approximately 1.5 times the maximum input voltage. Caution must be exercised if solid tantalum capacitors are used (see Application Information on input capacitor). The tantalum capacitor voltage rating should be 2 times the maximum input voltage and it is recommended that they be surge current tested by the manufacturer. Use caution when using ceramic capacitors for input bypassing, because it may cause severe ringing at the V_{IN} pin. **For additional information, see section on input capacitors in Application Information section.**	**4. Input Capacitor (C_{IN})** The important parameters for the Input capacitor are the input voltage rating and the RMS current rating. With a nominal input voltage of 12V, an aluminum electrolytic capacitor with a voltage rating greater than 18V (1.5 x V_{IN}) would be needed. The next higher capacitor voltage rating is 25V. The RMS current rating requirement for the input capacitor in a buck regulator is approximately ½ the DC load current. In this example, with a 3A load, a capacitor with a RMS current rating of at least 1.5A is needed. The curves shown in *Figure 13* can be used to select an appropriate input capacitor. From the curves, locate the 35V line and note which capacitor values have RMS current ratings greater than 1.5A. A 680 µF/35V capacitor could be used. For a through hole design, a 680 µF/35V electrolytic capacitor (Panasonic HFQ series or Nichicon PL series or equivalent) would be adequate. other types or other manufacturers capacitors can be used provided the RMS ripple current ratings are adequate. For surface mount designs, solid tantalum capacitors can be used, but caution must be exercised with regard to the capacitor surge current rating (see Application Information on input capacitors in this data sheet). The TPS series available from AVX, and the 593D series from Sprague are both surge current tested.

DESIGN PROCEDURE (FIXED OUTPUT)

Conditions			Inductor		Output Capacitor			
					Through Hole Electrolytic		Surface Mount Tantalum	
Output Voltage (V)	Load Current (A)	Max Input Voltage (V)	Inductance (μH)	Inductor (#)	Panasonic HFQ Series (μF/V)	Nichicon PL Series (μF/V)	AVX TPS Series (μF/V)	Sprague 595D Series (μF/V)
3.3	3	5	22	L41	470/25	560/16	330/6.3	390/6.3
		7	22	L41	560/35	560/35	330/6.3	390/6.3
		10	22	L41	680/35	680/35	330/6.3	390/6.3
		40	33	L40	560/35	470/35	330/6.3	390/6.3
	2	6	22	L33	470/25	470/35	330/6.3	390/6.3
		10	33	L32	330/35	330/35	330/6.3	390/6.3
		40	47	L39	330/35	270/50	220/10	330/10
5	3	8	22	L41	470/25	560/16	220/10	330/10
		10	22	L41	560/25	560/25	220/10	330/10
		15	33	L40	330/35	330/35	220/10	330/10
		40	47	L39	330/35	270/35	220/10	330/10
	2	9	22	L33	470/25	560/16	220/10	330/10
		20	68	L38	180/35	180/35	100/10	270/10
		40	68	L38	180/35	180/35	100/10	270/10
12	3	15	22	L41	470/25	470/25	100/16	180/16
		18	33	L40	330/25	330/25	100/16	180/16
		30	68	L44	180/25	180/25	100/16	120/20
		40	68	L44	180/35	180/35	100/16	120/20
	2	15	33	L32	330/25	330/25	100/16	180/16
		20	68	L38	180/25	180/25	100/16	120/20
		40	150	L42	82/25	82/25	68/20	68/25

Figure 3. LM2596 Fixed Voltage Quick Design Component Selection Table

DESIGN PROCEDURE (ADJUSTABLE OUTPUT)

PROCEDURE (Adjustable Output Voltage Version)	EXAMPLE (Adjustable Output Voltage Version)
Given: V_{OUT} = Regulated Output Voltage V_{IN}(max) = Maximum Input Voltage I_{LOAD}(max) = Maximum Load Current F = Switching Frequency *(Fixed at a nominal 150 kHz).*	**Given:** V_{OUT} = 20V V_{IN}(max) = 28V I_{LOAD}(max) = 3A F = Switching Frequency *(Fixed at a nominal 150 kHz).*
1. Programming Output Voltage (Selecting R_1 and R_2, as shown in *Figure 1*) Use the following formula to select the appropriate resistor values. $$V_{OUT} = V_{REF}\left(1 + \frac{R_2}{R_1}\right) \quad \text{where } V_{REF} = 1.23V$$ Select a value for R_1 between 240Ω and 1.5 kΩ. The lower resistor values minimize noise pickup in the sensitive feedback pin. (For the lowest temperature coefficient and the best stability with time, use 1% metal film resistors.) $$R_2 = R_1\left(\frac{V_{OUT}}{V_{REF}} - 1\right)$$	**1. Programming Output Voltage** (Selecting R_1 and R_2, as shown in *Figure 1*) Select R_1 to be 1 kΩ, 1%. Solve for R_2. $$R_2 = R_1\left(\frac{V_{OUT}}{V_{REF}} - 1\right) = 1k\left(\frac{20V}{1.23V} - 1\right)$$ R_2 = 1k (16.26 − 1) = 15.26k, closest 1% value is 15.4 kΩ. R_2 = 15.4 kΩ.
2. Inductor Selection (L1) **A.** Calculate the inductor Volt • microsecond constant E • T (V • µs), from the following formula: $$E \bullet T = (V_{IN} - V_{OUT} - V_{SAT}) \bullet \frac{V_{OUT} + V_D}{V_{IN} - V_{SAT} + V_D} \bullet \frac{1000}{150\ kHz}\ (V \bullet \mu s)$$ where V_{SAT} = internal switch saturation voltage = 1.16V and V_D = diode forward voltage drop = 0.5V **B.** Use the E • T value from the previous formula and match it with the E • T number on the vertical axis of the Inductor Value Selection Guide shown in *Figure 7.* **C.** on the horizontal axis, select the maximum load current. **D.** Identify the inductance region intersected by the E • T value and the Maximum Load Current value. Each region is identified by an inductance value and an inductor code (LXX). **E.** Select an appropriate inductor from the four manufacturer's part numbers listed in *Figure 8.*	**2. Inductor Selection (L1)** **A.** Calculate the inductor Volt • microsecond constant (E • T), $$E \bullet T = (28 - 20 - 1.16) \bullet \frac{20 + 0.5}{28 - 1.16 + 0.5} \bullet \frac{1000}{150}\ (V \bullet \mu s)$$ $$E \bullet T = (6.84) \bullet \frac{20.5}{27.34} \bullet 6.67\ (V \bullet \mu s) = 34.2\ (V \bullet \mu s)$$ **B.** E • T = 34.2 (V • µs) **C.** I_{LOAD}(max) = 3A **D.** From the inductor value selection guide shown in *Figure 7*, the inductance region intersected by the 34 (V • µs) horizontal line and the 3A vertical line is 47 µH, and the inductor code is L39. **E.** From the table in *Figure 8*, locate line L39, and select an inductor part number from the list of manufacturers part numbers.

DESIGN PROCEDURE (ADJUSTABLE OUTPUT)

PROCEDURE (Adjustable Output Voltage Version)	EXAMPLE (Adjustable Output Voltage Version)
3. Output Capacitor Selection (C_{OUT}) **A.** In the majority of applications, low ESR electrolytic or solid tantalum capacitors between 82 µF and 820 µF provide the best results. This capacitor should be located close to the IC using short capacitor leads and short copper traces. Do not use capacitors larger than 820 µF. **For additional information, see section on output capacitors in application information section.** **B.** To simplify the capacitor selection procedure, refer to the quick design table shown in *Figure 3*. This table contains different output voltages, and lists various output capacitors that will provide the best design solutions. **C.** The capacitor voltage rating should be at least 1.5 times greater than the output voltage, and often much higher voltage ratings are needed to satisfy the low ESR requirements needed for low output ripple voltage.	**3. Output Capacitor Selection (C_{OUT})** **A.** See section on C_{OUT} in Application Information section. **B.** From the quick design table shown in *Figure 3*, locate the output voltage column. From that column, locate the output voltage closest to the output voltage in your application. In this example, select the 24V line. Under the output capacitor section, select a capacitor from the list of through hole electrolytic or surface mount tantalum types from four different capacitor manufacturers. It is recommended that both the manufacturers and the manufacturers series that are listed in the table be used. In this example, through hole aluminum electrolytic capacitors from several different manufacturers are available. 220 µF/35V Panasonic HFQ Series 150 µF/35V Nichicon PL Series **C.** For a 20V output, a capacitor rating of at least 30V or more is needed. In this example, either a 35V or 50V capacitor would work. A 35V rating was chosen, although a 50V rating could also be used if a lower output ripple voltage is needed. Other manufacturers or other types of capacitors may also be used, provided the capacitor specifications (especially the 100 kHz ESR) closely match the types listed in the table. Refer to the capacitor manufacturers data sheet for this information.
4. Feedforward Capacitor (C_{FF}) (See *Figure 1*) For output voltages greater than approximately 10V, an additional capacitor is required. The compensation capacitor is typically between 100 pF and 33 nF, and is wired in parallel with the output voltage setting resistor, R_2. It provides additional stability for high output voltages, low input-output voltages, and/or very low ESR output capacitors, such as solid tantalum capacitors. $C_{FF} = \frac{1}{31 \times 10^3 \times R_2}$ This capacitor type can be ceramic, plastic, silver mica, etc. (Because of the unstable characteristics of ceramic capacitors made with Z5U material, they are not recommended.)	**4. Feedforward Capacitor (C_{FF})** The table shown in *Figure 3* contains feed forward capacitor values for various output voltages. In this example, a 560 pF capacitor is needed.

DESIGN PROCEDURE (ADJUSTABLE OUTPUT)

PROCEDURE (Adjustable Output Voltage Version)	EXAMPLE (Adjustable Output Voltage Version)
5. Catch Diode Selection (D1) **A.** The catch diode current rating must be at least 1.3 times greater than the maximum load current. Also, if the power supply design must withstand a continuous output short, the diode should have a current rating equal to the maximum current limit of the LM2596. The most stressful condition for this diode is an overload or shorted output condition. **B.** The reverse voltage rating of the diode should be at least 1.25 times the maximum input voltage. **C.** This diode must be fast (short reverse recovery time) and must be located close to the LM2596 using short leads and short printed circuit traces. Because of their fast switching speed and low forward voltage drop, Schottky diodes provide the best performance and efficiency, and should be the first choice, especially in low output voltage applications. Ultra-fast recovery, or High-Efficiency rectifiers are also a good choice, but some types with an abrupt turn-off characteristic may cause instability or EMI problems. Ultra-fast recovery diodes typically have reverse recovery times of 50 ns or less. Rectifiers such as the 1N4001 series are much too slow and should not be used.	**5. Catch Diode Selection (D1)** **A.** Refer to the table shown in *Figure 11*. Schottky diodes provide the best performance, and in this example a 5A, 40V, 1N5825 Schottky diode would be a good choice. The 5A diode rating is more than adequate and will not be overstressed even for a shorted output.
6. Input Capacitor (C_{IN}) A low ESR aluminum or tantalum bypass capacitor is needed between the input pin and ground to prevent large voltage transients from appearing at the input. In addition, the RMS current rating of the input capacitor should be selected to be at least ½ the DC load current. The capacitor manufacturers data sheet must be checked to assure that this current rating is not exceeded. The curve shown in *Figure 13* shows typical RMS current ratings for several different aluminum electrolytic capacitor values. This capacitor should be located close to the IC using short leads and the voltage rating should be approximately 1.5 times the maximum input voltage. If solid tantalum input capacitors are used, it is recomended that they be surge current tested by the manufacturer. Use caution when using a high dielectric constant ceramic capacitor for input bypassing, because it may cause severe ringing at the V_{IN} pin. **For additional information, see section on input capacitors in application information section.**	**6. Input Capacitor (C_{IN})** The important parameters for the Input capacitor are the input voltage rating and the RMS current rating. With a nominal input voltage of 28V, an aluminum electrolytic aluminum electrolytic capacitor with a voltage rating greater than 42V (1.5 x V_{IN}) would be needed. Since the the next higher capacitor voltage rating is 50V, a 50V capacitor should be used. The capacitor voltage rating of (1.5 x V_{IN}) is a conservative guideline, and can be modified somewhat if desired. The RMS current rating requirement for the input capacitor of a buck regulator is approximately ½ the DC load current. In this example, with a 3A load, a capacitor with a RMS current rating of at least 1.5A is needed. The curves shown in *Figure 13* can be used to select an appropriate input capacitor. From the curves, locate the 50V line and note which capacitor values have RMS current ratings greater than 1.5A. Either a 470 µF or 680 µF, 50V capacitor could be used. For a through hole design, a 680 µF/50V electrolytic capacitor (Panasonic HFQ series or Nichicon PL series or equivalent) would be adequate. Other types or other manufacturers capacitors can be used provided the RMS ripple current ratings are adequate. For surface mount designs, solid tantalum capacitors can be used, but caution must be exercised with regard to the capacitor surge current rting (see Application Information or input capacitors in this data sheet). The TPS series available from AVX, and the 593D series from Sprague are both surge current tested. *To further simplify the buck regulator design procedure, National Semiconductor is making available computer design software to be used with the Simple Switcher line ot switching regulators. **Switchers Made Simple** (version 4.3 or later) is available on a 3½" diskette for IBM compatible computers.*

DESIGN PROCEDURE (ADJUSTABLE OUTPUT)

Output Voltage (V)	Through Hole Output Capacitor			Surface Mount Output Capacitor		
	Panasonic HFQ Series (μF/V)	Nichicon PL Series (μF/V)	Feedforward Capacitor	AVX TPS Series (μF/V)	Sprague 595D Series (μF/V)	Feedforward Capacitor
2	820/35	820/35	33 nF	330/6.3	470/4	33 nF
4	560/35	470/35	10 nF	330/6.3	390/6.3	10 nF
6	470/25	470/25	3.3 nF	220/10	330/10	3.3 nF
9	330/25	330/25	1.5 nF	100/16	180/16	1.5 nF
1 2	330/25	330/25	1 nF	100/16	180/16	1 nF
1 5	220/35	220/35	680 pF	68/20	120/20	680 pF
2 4	220/35	150/35	560 pF	33/25	33/25	220 pF
2 8	100/50	100/50	390 pF	10/35	15/50	220 pF

Figure 4. Output Capacitor and Feedforward Capacitor Selection Table

Inductor Manufacturers Part Numbers

	Inductance (μH)	Current (A)	Schott		Renco		Pulse Engineering		Coilcraft
			Through Hole	Surface Mount	Through Hole	Surface Mount	Through Hole	Surface Mount	Surface Mount
L15	22	0.99	67148350	67148460	RL-1284-22-43	RL1500-22	PE-53815	PE-53815-S	DO3308-223
L21	68	0.99	67144070	67144450	RL-5471-5	RL1500-68	PE-53821	PE-53821-S	DO3316-683
L22	47	1.17	67144080	67144460	RL-5471-6	—	PE-53822	PE-53822-S	DO3316-473
L23	33	1.40	67144090	67144470	RL-5471-7	—	PE-53823	PE-53823-S	DO3316-333
L24	22	1.70	67148370	67148480	RL-1283-22-43	—	PE-53824	PE-53825-S	DO3316-223
L25	15	2.10	67148380	67148490	RL-1283-15-43	—	PE-53825	PE-53824-S	DO3316-153
L26	330	0.80	67144100	67144480	RL-5471-1	—	PE-53826	PE-53826-S	DO5022P-334
L27	220	1.00	67144110	67144490	RL-5471-2	—	PE-53827	PE-53827-S	DO5022P-224
L28	150	1.20	67144120	67144500	RL-5471-3	—	PE-53828	PE-53828-S	DO5022P-154
L29	100	1.47	67144130	67144510	RL-5471-4	—	PE-53829	PE-53829-S	DO5022P-104
L30	68	1.78	67144140	67144520	RL-5471-5	—	PE-53830	PE-53830-S	DO5022P-683
L31	47	2.20	67144150	67144530	RL-5471-6	—	PE-53831	PE-53831-S	DO5022P-473
L32	33	2.50	67144160	67144540	RL-5471-7	—	PE-53932	PE-53932-S	DO5022P-333
L33	22	3.10	67148390	67148500	RL-1283-22-43	—	PE-53933	PE-53933-S	DO5022P-223
L34	15	3.40	67148400	67148790	RL-1283-15-43	—	PE-53934	PE-53934-S	DO5022P-153
L35	220	1.70	67144170	—	RL-5473-1	—	PE-53935	PE-53935-S	—
L36	150	2.10	67144180	—	RL-5473-4	—	PE-54036	PE-54036-S	—
L37	100	2.50	67144190	—	RL-5472-1	—	PE-54037	PE-54037-S	—
L38	68	3.10	67144200	—	RL-5472-2	—	PE-54038	PE-54038-S	—
L39	47	3.50	67144210	—	RL-5472-3	—	PE-54039	PE-54039-S	—
L40	33	3.50	67144220	67148290	RL-5472-4	—	PE-54040	PE-54040-S	—
L41	22	3.50	67144230	67148300	RL-5472-5	—	PE-54041	PE-54041-S	—
L42	150	2.70	67148410	—	RL-5473-4	—	PE-54042	PE-54042-S	—
L43	100	3.40	67144240	—	RL-5473-2	—	PE-54043		—
L44	68	3.40	67144250	—	RL-5473-3	—	PE-54044		—